4.0 Incorporating Commercial Vehicles into the Travel Forecasting Process

■ 4.1 Introduction

This chapter describes a simplified quick-response procedure for incorporating commercial vehicles into the travel forecasting processes used by Metropolitan Planning Organizations, State Departments of Transportation, and other planning agencies. This chapter also provides alternative approaches that might be used if more data are available (or can be collected) and more accuracy is desired.

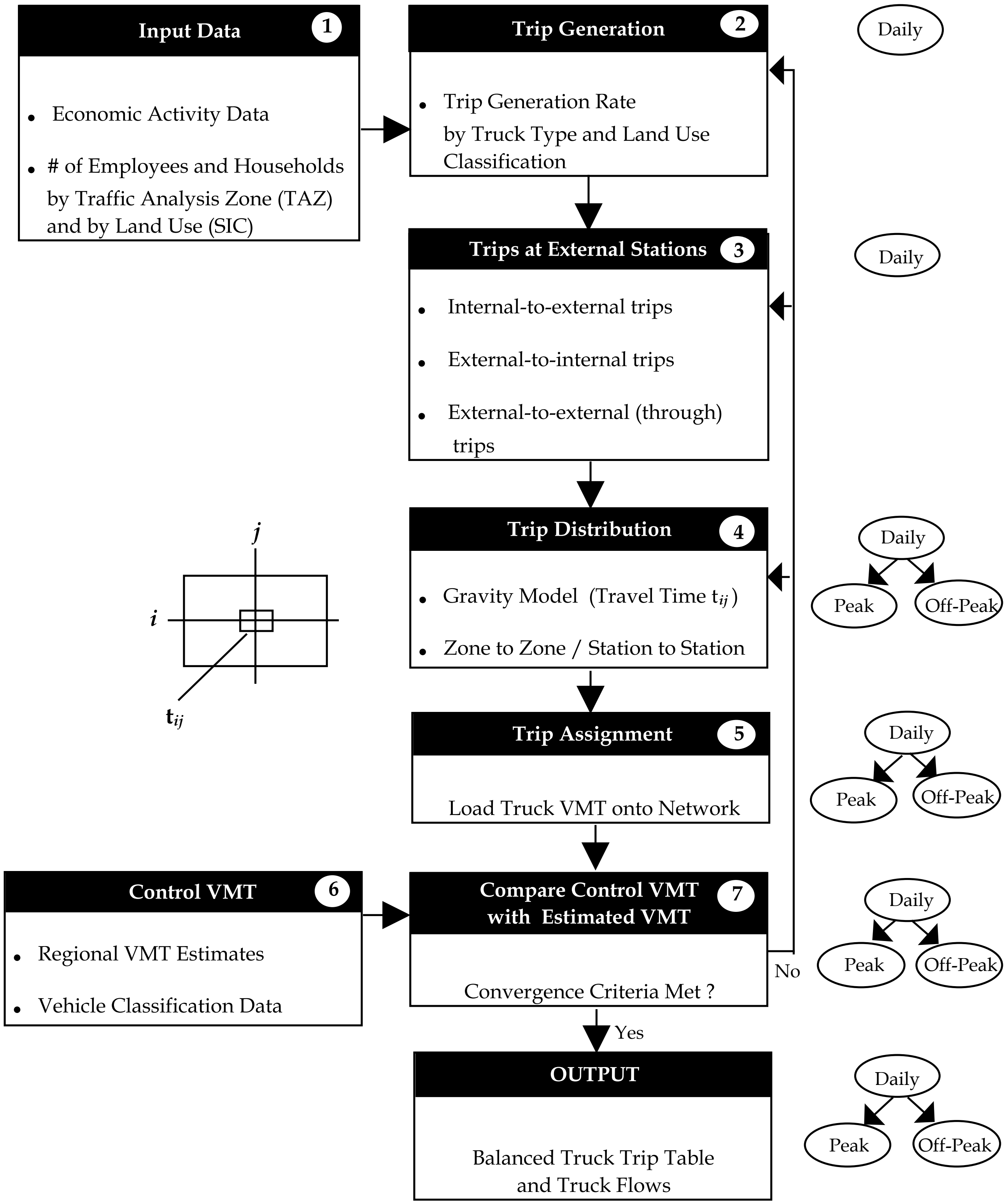
The procedure produces trip tables that can be assigned to highway networks for three classes of commercial vehicles:

- Four-tire commercial vehicles, including delivery and service vehicles,
- Single unit trucks with six or more tires,
- Combination trucks consisting of a power unit (truck or tractor) and one or more trailing units.

Figure 4.1 shows the simplified quick-response procedure as consisting of the following steps:

1. Obtain data on economic activity for traffic analysis zones (including employment by type and the number of households),
2. Apply trip generation rates to estimate the number of commercial vehicle trip destinations for each traffic analysis zone,
3. Estimate commercial vehicle volumes at external stations,
4. Estimate the number of commercial vehicle trips between pairs of traffic analysis zones or external stations,
5. Develop a preliminary estimate of commercial vehicle VMT by assigning trips to a network (or using a table of zone-to-zone distances),

Figure 4.1 Simplified Quick Response Freight Forecasting Procedure



6. Develop control totals for commercial VMT based upon (1) estimates of total VMT in the region for each functional class, and (2) vehicle classification data indicating the percentage of total VMT associated with commercial vehicles

7. Compare the results of Step 5 and Step 6, and, if necessary, develop adjustment factors to trip generation rates or trip distribution factors.

Steps 2 through 7 are repeated until the estimates of commercial vehicle VMT developed in Step 5 is reasonably close to the control totals developed in Step 6. The following sections describe each of these steps. A hypothetical example is included to illustrate the procedures.

Finally, a section on time-of-day characteristics discusses the temporal distribution of travel by commercial vehicles.

4.2 Trip Generation

In the quick-response procedure, the number of commercial vehicle destinations per day in each traffic analysis zone is calculated by:

- Estimating (or obtaining data on) the number of employees who work in the traffic analysis zone for each of the following employment categories:

  1. Agriculture, Mining and Construction (SIC 1-19)

  2. Manufacturing, Transportation/Communications/Utilities and Wholesale Trade (SIC 20-51)

  3. Retail Trade (SIC 52-59)

  4. Office and Services (SIC 60-88),

- Estimating (or obtaining data on) the number of households located in the traffic analysis zone,

- Applying the trip generation rates shown in Table 4.1 to the data obtained above.

The trip generation rates shown in Table 4.1 are for trip destinations (which, on an average day, are equal to trip origins). These rates were taken from a Phoenix, Arizona study[1,2]. The Phoenix study results are used as the basis for default values because they

[1] Earl Ruiter; Cambridge Systematics, Inc.; *Development of an Urban Truck Travel Model for the Phoenix Metropolitan Area*; February 1992; Report Number FHWA-AZ92-314; prepared for Arizona Department of Transportation and the Federal Highway Administration.

provide an internally-consistent set of trip generation rates and trip times, compared with potentially inaccurate rates derived from mixing results from a large number of studies in which the exact trip generations, vehicle definitions and employment categories used are mostly unclear or unknown. Appendix D, however, contains site-specific trip generation rates and regression equations that a user may find more suitable for a particular state or region being analyzed.

Table 4.1 Trip Generation Rates

Generator	Commercial Vehicle Trip Destinations (or Origins) per Unit per Day			
	Four -Tire Vehicles	Single Unit Trucks (6+ Tires)	Combinations	TOTAL
Employment: *				
• Agriculture, Mining and Construction	1.110	0.289	0.174	1.573
• Manufacturing, Transportation, Communications, Utilities and Wholesale Trade	0.938	0.242	0.104	1.284
• Retail Trade	0.888	0.253	0.065	1.206
• Office and Services	0.437	0.068	0.009	0.514
Households	0.251	0.099	0.038	0.388

* If employment data is available only in terms of retail and non-retail employment, the trip generation rates shown above for non-retail employment should be weighted by the following national employment average percentages: (1) Agriculture, Mining and Construction - 10.9%; (2) Manufacturing, Transportation, Communications, Utilities and Wholesale Trade - 29.5%, (3) Office and Services - 59.6%.

Information on the number of households and employees by traffic analysis zone may be available to States or metropolitan/regional planning agencies through local data used for passenger transportation planning. If not, other sources and methodologies may be used including allocation of business-specific county or zip code data to census tracts.

For example, *County Business Patterns* presents county-level data on establishments (total and by employment size class) as well as total employment by SIC code (see Appendix C for listing and description of SIC codes). This data is tabulated by industry as defined

[2] The trip generation rates in Table 4.1 were increased to account for under-reporting and the fact that the survey did not cover trips with one end outside the region. The rates for combinations were increased disproportionately because combinations tend to be used for intercity shipments to a much greater degree than the other two classes of commercial vehicles.

in the 1987 *Standard Industrial Classification (SIC) Manual*. This tabulation is consistent with the classification methods used to create the default values in Table 4.1.

The same categories may also be obtained at the zip code level by special order from the Bureau of Census.[3]

County Business Patterns examines activity by specific sites or establishments. An establishment is a single physical location at which business is conducted or services or industrial operations are performed. It is not necessarily identical with a company or enterprise, which may consist of one or more establishments. When two or more activities are carried on at a single location under a single ownership, all activities generally are grouped together as a single establishment. For example, the administrative and shipping personnel of a manufacturing facility will be classified as manufacturing. However, administrative and auxiliary establishments that primarily manage or support the activities of other establishments of the same company (such as the headquarters of a multi-establishment conglomerate) are shown separately by industry division.

County Business Pattern data by major SIC code and by zip code may be allocated to associated census tracts where there is reasonable correspondence, based on total employment in each census tract from the *Census Transportation Planning Package* (CTPP). Comparisons of total employment between the two data sources should be performed, recognizing that County Business Patterns excludes self-employed and government workers, and that CTPP includes 1990 Census data. Local knowledge should also be employed to fine-tune allocations. For example, if County Business Patterns identifies 2,000 persons engaged in manufacturing employment in a zip code area, and the regional planning organization knows that the manufacturing site in a single census tract employs approximately that many people, it is appropriate to allocate the zip code manufacturing employment to that single census tract, rather than distribute it among all census tracts in the zip code area.

A general caution in using Bureau of Economic Analysis (BEA) or Census data for employment is that in some cases a headquarters office or central administrative facility is used as the address for dispersed activities such as construction, transportation, or electric and gas utilities. Data are excluded for self-employed persons, domestic service workers, railroad employees, agricultural production workers, most government employees, and employees on ocean-borne vessels or in foreign countries.

If the planning agency cannot secure employment by business type at the regional, county or zip code level, analysis can be performed using total employment by census tract. Under this method (not recommended for quick-response freight planning) total employment by census tract is multiplied by the average trip generation rate per employee. Employment by census tract is available from the CTPP. It includes tabulations by small areas of work, which are traffic analysis zones (TAZ's) in areas where the MPO supplied block-to-zone correspondence (Part 2 in MPO tabulations) and tabulations by census tract of work (Part 7 in MPO tabulations). Tabulations for CTPP do not include business type.

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[3] Efforts are currently underway to increase accessibility to this data . See Appendix K, Part 1.

To achieve a higher level of accuracy, it is necessary to identify employment by type and by census tract or TAZ, rather than allocate from zip code or county level. If even greater accuracy is desired, commercial data sources can provide detailed information in various formats, including employment by census tract and by SIC code (see Chapter 6 and Appendix L for details).

4.2.1 Example

Figure 4.2 shows a hypothetical study area consisting of three traffic analysis zones (TAZ's) and a number of major radial and circumferential highways. Four external stations have also been designated for the study area as shown.

Data on employment and number of households for each zone in the study area are given in the table below.

Number of Households and Employees in Each Zone

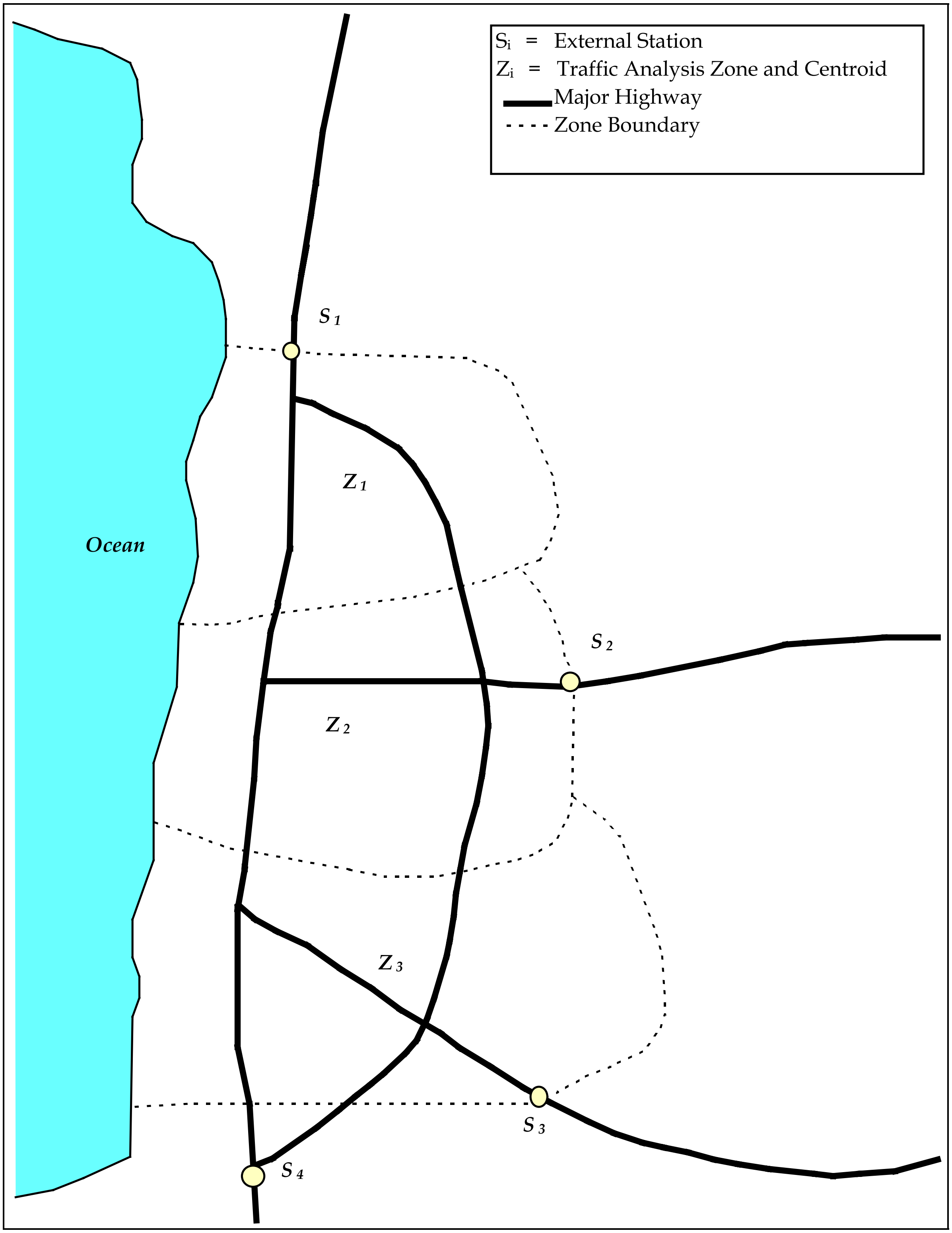
	Zone		
Land Use Type	**Z_1**	**Z_2**	**Z_3**
No. of Households	3,120	4,364	5,985
No. of Employees:			
Agriculture, Mining and Construction	0	0	0
Manufacturing, Transportation/ Communications/Utilities and Wholesale Trade	6,241	9,362	20,209
Retail Trade	8,916	17,831	7,430
Office and Services	23,775	8,916	5,944
Total Employment	38,932	36,109	33,583

Multiplying the numbers in this table with the trip generation rates in Table 4.1 gives the estimated number of commercial vehicle destinations per day for each vehicle type in each zone. For example, the estimated number of 4-tire commercial vehicle destinations generated by office/services employees for Zone Z_1 is:

= [23,775] * [0.437] = 10,390 destinations/day.

Figure 4.2 Map of Hypothetical Study Area for the Example

The estimated total daily commercial vehicle destinations generated for the vehicle types and land use classification in the three zones are shown in the tables below.



Estimated Total Daily 4-Tire Commercial Vehicle Destinations Generated

	Zone		
Land Use Type	**Z_1**	**Z_2**	**Z_3**
Households	783	1,095	1,502
Employees:			
Agriculture, Mining and Construction	0	0	0
Manufacturing, Transportation/ Communications/Utilities and Wholesale Trade	5,854	8,782	18,956
Retail Trade	7,917	15,834	6,598
Office and Services	10,390	3,896	2,598
TOTAL	24,944	29,607	29,654

Estimated Total Daily Single Unit (6+ tire) Commercial Vehicle Destinations Generated in Each Zone

	Zone		
Land Use Type	**Z_1**	**Z_2**	**Z_3**
Households	309	432	593
Employees:			
Agriculture, Mining and Construction	0	0	0
Manufacturing, Transportation/ Communications/Utilities and Wholesale Trade	1,510	2,266	4,891
Retail Trade	2,256	4,511	1,880
Office and Services	1,617	606	404
TOTAL	5,692	7,815	7,767

Estimated Total Daily Combination Vehicle Destinations Generated in Each Zone

Land Use Type	Zone Z_1	Z_2	Z_3
Households	119	166	227
Employees:			
Agriculture, Mining and Construction	0	0	0
Manufacturing, Transportation/ Communications/Utilities and Wholesale Trade	649	974	2,102
Retail Trade	580	1,159	483
Office and Services	214	80	53
TOTAL	1,561	2,379	2,866

The total estimated daily commercial vehicle destinations generated for each land use type in each zone and the total trips for all zones are shown in the table below.

Estimated Total Daily Commercial Vehicle Destinations Generated for Each Vehicle Type and Zone

Vehicle Type	Zone Z_1	Z_2	Z_3	TOTAL
4-Tire Trucks	24,944	29,607	29,654	84,205
Single Unit (6+ Tire) Trucks	5,692	7,815	7,767	21,274
Combination Vehicles	1,561	2,379	2,866	6,806
All Commercial Vehicles	32,197	**39,801**	**40,287**	**112,285**

4.2.2 Alternative Approaches

As stated above, the trip generation rates proposed in the quick response method were derived from Phoenix, Arizona data. In many situations one would want to use site-specific trip generation rates particularly if the site characteristics are very much different from the Phoenix area. In addition, the trip generation rates presented in Table 4.1 are for four groups of land use or industrial classification. Each group pertains to several specific land use and employment characteristics (see Appendix C for Standard Industrial Classification (SIC) codes). More accurate estimates of commercial vehicle trips can be obtained using trip generation rates that correspond to specific land use or industrial classification, if the employment data as well as trip generation rates exist for the specific employment category.

Tables D-1a through D-1d in Appendix D contain trip generation rates (per employee) gathered from a large number of locations throughout the United States and Australia.[4] The tables are arranged according to the four groups of SIC codes pertaining to the land use classification in Table 4.1. Specific SIC codes for some trip generation rates in many locations have been identified (e.g. SIC 42 for Truck Transportation). This information can be very useful in detailed site analysis and planning for specific types of establishments, and for more accurate estimation of commercial vehicle trip generation in a traffic analysis zone. Land use types that could not be classified under any one of the SIC codes are shown in Table D-1e.

Chapter 6 also presents other data collection methods and data sources pertaining to truck trip generation. Chapter 5 also describes procedures for estimating trip generation rates for major intermodal facilities and other special trip generators.

If employment data are not available for estimating commercial vehicle trips, other measures of economic activity such as total floor space or total land area devoted to specific employment categories can be used. Trip generation rates per one thousand square feet (TSF) and per acre of various employment (SIC) categories are shown in Table D-2b through D-2e, and Table D-3a through D-3e, respectively. These tables are arranged according to SIC codes (similar to Table D-1). Tables D-2e and D-3e contain trip generation rates for sites whose land use category cannot be classified under any one of the SIC codes.

More elaborate procedures (compared to the one-variable, fixed-rate approach in the quick response method) for predicting commercial vehicle trips involve various forms of equations as well as more than one independent variable. These equations have been developed and calibrated using a variety of estimation techniques, most commonly the ordinary least squares regression. Table D-4a through D-4e summarize some of the regression equations developed from various site studies and which can be used for predicting number of commercial vehicle trips as a function of one or more variables. If

[4] The trip generation rates shown for Phoenix, Arizona in Appendix D are the unadjusted rates reported in the Ruiter study. See Footnote 1.

the required information exists, these equations can produce more accurate trip generation estimates compared with the simple fixed-rate approach.

■ 4.3 External Stations

Most metropolitan area and regional travel forecasting networks include external stations through which trips with one or both ends outside the study area are loaded onto the network. Trips through external stations include:

- Internal-to-external trips which begin in a traffic analysis zone and end outside the study area;
- External-to-internal trips which begin outside the study area and end in a traffic analysis zone; and
- External-to-external (through) trips which begin and end outside the study area.

These trips are usually classified into one of the following four categories:

1. Passenger vehicles (which may be subdivided into Light vehicles and Buses),
2. Four-tire commercial vehicles,
3. Single unit trucks with six or more tires, and
4. Combination vehicles.

In the quick-response procedure, commercial vehicle volumes at external stations may be estimated by applying percentages to estimate volumes for each of the three commercial vehicle classes based on the functional classification of the highway.

In some cases, however, a comprehensive data gathering effort to determine actual volumes and vehicle classifications at external stations (possibly including an origin-destination survey, see Chapter 6) may be warranted as a means for estimating volumes for each of the three commercial vehicle classes. Such effort will be particularly useful for a small study area and/or an area with significant volumes of through trips. Sources of actual data include traffic counts using field surveys, weigh-in-motion equipment or pneumatic tubes. Field counts will generally include truck counts by truck class (axles/weight or both), site, roadway type and time of day, usually accumulated as parts of other studies from one or combinations of the following:

- HPMS counts (visual and automated)
- Turning-vehicle-movement counts
- Weigh-in-Motion counts and classifications

- Turnpike or bridge-toll counts
- Weigh-station counts and records
- Site studies (counts and forecasts)
- Safety studies
- Cordon counts
- Origin-destination surveys

It may be necessary to perform new counts on major external stations with old, suspect or missing data. Select data from sites near the border of the region in question, preferably without intervening roads to add or divert traffic. If data are available for a broad representation of lane and highway classifications, it is possible to expand the data to lanes and highways that were not sampled.

Agencies should be alert to a number of cautions and potential definitional problems in all counts related to freight movement, both internal and external. Research suggests wide variances in truck counts or classifications based on tube counts due to equipment calibrations, vehicle speed and traffic density. Therefore caution should be exercised in applying tube counts for vehicle classification to the model. Weigh-in-motion data, and even some visual classification schemes, may not clearly identify small commercial vehicles from other four-tired vehicles such as autos and vans. Further, truck classifications such as pickups, mini-vans and panel or full-sized vans are used for personal transportation as well as business applications. A key parameter of freight forecasting is to identify and model vehicle trips which are not typically captured in a household survey. If the survey or classification method does not clearly distinguish between personal and commercial vehicle use, then counts of pickups, mini-vans and panel or full vans should be discounted by the number of vehicles used for personal transportation. The 1992 Truck Inventory and Use Survey (TIUS) identifies the national average commercial use percentages for these vehicle types:

- Pickup - 32.2 %
- Mini-van - 25 %
- Panel or full-size van - 45.7 %

As illustrated below, these percentages can be applied to counts of four-tire trucks to estimate commercial vehicle traffic:

Type	Total Count	Percent Commercial	4-Tire Commercial Vehicle
Pickups	1,200	32.2%	386
Mini-vans	500	25.0%	125
Panels or Vans	400	45.7%	183
TOTAL	2,100		694

If it is not practical to conduct traffic count and classification studies at external stations, the default percentages shown in Table 4.2 may be used to obtain estimates of volumes at external stations for each of the three commercial vehicle classes. The percentages are based on: (1) vehicle classification data collected by States and compiled by the Federal Highway Administration, and (2) information from the Bureau of the Census' Truck Inventory and Use Survey (TIUS) on the use of light trucks[5].

Table 4.2 Percent Distribution of Traffic by Vehicle Class

Functional Class	Non-Commercial Vehicles	Commercial Vehicles			Total
		Four-Tire	Single Unit	Combination	
RURAL					
Interstate	81.6%	3.3%	2.9%	12.2%	100%
Other Principal Arterials	87.2%	4.7%	3.2%	4.9%	100%
Minor Arterial, Collector and Local	88.5%	5.3%	3.6%	2.6%	100%
Average - Rural	86.6%	4.7%	3.4%	5.3%	100%
URBAN					
Interstate	88.2%	5.5%	1.8%	4.5%	100%
Other Freeways and Expressways	90.5%	5.5%	1.7%	2.3%	100%
Other Principal Arterials	89.5%	6.6%	1.7%	2.2%	100%
Minor Arterials	90.4%	6.4%	1.7%	1.5%	100%
Collectors	90.3%	6.4%	1.8%	1.5%	100%
Local	91.0%	6.4%	1.8%	0.8%	100%
Average - Urban	89.8%	6.2%	1.7%	2.3%	100%

Source: Vehicle Classification Data of FHWA and Census' Truck Inventory User Survey.

If data on average daily traffic for all vehicles at one or more external stations are not available, data on annual average daily traffic per lane from *the Highway Performance Monitoring System* (HPMS) database can be used to estimate AADT (see Table 4.3 below). The minimum information needed to accomplish this method is an inventory of the number of lanes by functional class, classified as urban or rural, for all highways where the stations are located. However, it should be noted that the variability in AADT per

[5] Specifically, the TIUS was used to estimate the percentage of VMT by four-tire trucks associated with personal use. In Table 4.2, personal use VMT by four-tire trucks is included in the "Non-Commercial Vehicles" column.

lane across facilities and geographic areas is huge, and estimates of AADT based on the default values given in Table 4.3 could be off by an order of magnitude, as indicated by the 10th percentile and 90th percentile values of traffic volumes in the HPMS database as shown in the table.

Table 4.3 Annual Average Daily Traffic (AADT) per Lane

Functional Class		2-Lanes	4-Lanes	6-Lanes	8-Lanes	10-Lanes
RURAL						
Interstate						
	Average	2,581	4,251	8,500	9,004	----
	10th %-ile	304	1,493	4,613	5,888	----
	90th %-ile	20,355	7,325	13,299	15,788	----
Other Principal Arterial						
	Average	2,268	3,159	7,100	----	----
	10th %-ile	671	975	3,416	----	----
	90th %-ile	4,432	6,425	9,546	----	----
Minor Arterial						
	Average	1,758	2,752	7,878	----	----
	10th %-ile	335	712	5,047	----	----
	90th %-ile	3,900	5,518	16,533	----	----
Major Collector						
	Average	1,062	2,774	4,970	----	----
	10th %-ile	84	650	2,183	----	----
	90th %-ile	2,665	5,909	8,167	----	----
Minor Collector						
	Average	407	926	----	----	----
	10th %-ile	24	79	----	----	----
	90th %-ile	1,035	2,500	----	----	----
URBAN						
Interstate						
	Average	8,321	8,649	12,940	15,700	16,654
	10th %-ile	3,115	3,020	6,249	8,160	10,579
	90th %-ile	15,300	15,063	21,000	23,865	23,420
Other Freeways/Expressways						
	Average	6,887	7,448	11,932	17,084	19,145
	10th %-ile	2,420	2,495	4,140	7,000	14,330
	90th %-ile	13,475	14,000	21,500	26,638	25,965
Other Principal Arterials						
	Average	4,823	4,924	6,075	6,936	----
	10th %-ile	1,500	1,833	2,650	2,743	----
	90th %-ile	9,000	8,550	9,779	10,918	----
Minor Arterials						
	Average	3,242	3,993	4,747	5,004	----
	10th %-ile	705	1,335	2,200	1,500	----
	90th %-ile	6,748	7,065	8,200	10,594	----
Collectors						
	Average	1,737	2,696	3,243	----	----
	10th %-ile	285	528	1,286	----	----
	90th %-ile	4,025	5,407	5,793	----	----

Source: Highway Performance Monitoring System (HPMS) Database, Federal Highway Administration

4.3.1 Example

To illustrate the methods discussed above, the characteristics of the four external stations in the hypothetical study area shown in Figure 4.2 are given in the table below:

Characteristics of External Stations in Hypothetical Study Area

	External Station			
Characteristic	**S_1**	**S_2**	**S_3**	**S_4**
Functional Class	Urban Interstate	Rural Interstate	Urban Principal Arterial	Urban Interstate
No. of Lanes	8	6	4	8
AADT per Lane	13,400	9,100	not available	11,500

No vehicle classification data are available, hence the composition of traffic at these external stations is unknown. Using Table 4.2 and Table 4.3, the total commercial vehicle trips at each station can be estimated as shown in the table below:

Estimated Daily Vehicle Trips at External Stations

	External Station				
Characteristics	S1	S2	S3	S4	Total
Functional Class	Urban Interstate	Rural Interstate	Urban Princ. Arterial	Urban Interstate	
AADT per Lane	13,400	9,100	4,924 (Table 4.3)	11,500	
No. of Lanes	8	6	4	8	
AADT	107,200	54,600	19,696	92,000	
<u>% Distribution:</u>	(from Table 4.2)	(from Table 4.2)	(from Table 4.2)	(from Table 4.2)	
Four-Tire	5.50%	3.30%	6.60%	5.50%	
Single Unit	1.80%	2.90%	1.70%	1.80%	
Combination	4.50%	12.20%	2.20%	4.50%	
<u>Truck AADT: (2-Way)</u>					
Four-Tire	5,896	1,802	1,300	5,060	14,058
Single Unit	1,930	1,583	335	1,656	5,504
Combination	4,824	6,661	433	4,140	16,059
Total	12,650	10,046	2,068	10,856	35,620
<u>Truck AADT: (1-Way)</u>					
Four-Tire	2,948	901	650	2,530	7,029
Single Unit	965	792	167	828	2,752
Combination	2,412	3,331	217	2,070	8,029
Total	6,325	5,023	1,034	5,428	17,810

4.3.2 Alternative Approaches

Chapter 6 provides additional detail on how to obtain more accurate data on external stations by conducting vehicle classification counts and origin-destination surveys at major external stations to develop external-external, external-internal and internal-external trip tables. Surveys at external stations, in which individual vehicles are stopped and asked about their origin and destination, are the preferred method for analyzing traffic at these stations. However, as stated earlier, budget limitations or other constraints may prevent the agency from conducting such surveys at all external stations. If such surveys are not possible, the agency should consider the possibility of at least conducting traffic classification counts at external stations, either manually or by using automatic classification equipment.

■ 4.4 Trip Distribution

Trip distribution is the process by which trips between traffic analysis zones, or between external stations, are connected. The output of trip distribution is a trip table in which the origins and destinations of individual trips are identified.

The quick-response procedure uses the following standard gravity model for trip distribution:

$$V_{ij} = \frac{O_i D_j F_{ij}}{\sum_{j=1}^{n} D_j F_{ij}}$$

where

V_{ij} = trips (volume) originating at analysis area i and destined to analysis area j;
O_i = total trip originating at i;
D_j = total trip destined at j;
F_{ij} = friction factor for trip interchange ij,
i = origin analysis area number, $i = 1, 2, 3 \ldots n$;
j = destination analysis area number, $j = 1, 2, 3 \ldots n$; and
n = number of analysis areas.

Applying the above equation for each zone pair can result in a trip table in which the total number of trips ending in a given zone differs significantly from the desired number of destinations (D_j). To address this problem, the Gravity Model can be applied in an iterative manner. After each iteration, the adjusted destination total to be used for the next iteration is calculated by the following equation:

$$D_j^q = D_j^{q-1} \bullet \frac{D_j}{C_j^{q-1}}$$

where

D_j^q =adjusted destination factor for destination analysis area (column) j, iteration q;
D_j^{q-1} =D_j when $q = 1$;
C_j^{q-1} =destination (column) total for analysis area j, resulting from the previous iteration of the gravity model;
D_j=original and desired destination total for destination analysis area (column) j, developed from trip generation;
j =destination analysis area, $j = 1, 2, \ldots n$;
n =number of analysis areas; and
q =iteration number.

For the quick response procedure involving manual calculations, it would be tedious to perform more than three iterations using the above equation, especially if the study area consists of numerous zones. The option to iterate more depends upon the level of accuracy required which is the percentage difference between the destination totals at the end of each iteration and that originally input for each analysis area. According to the NCHRP Report No. 187 - *Quick-Response Urban Travel Estimation Techniques and Transferable Parameters Users Guide*[6], a 5- to 10- percent difference is generally acceptable. However, these levels of accuracy may not be attained within three iterations. A computer program may be utilized if the planning agency wishes to achieve a certain accuracy level without manually going through multiple iterations.

Friction factors (F_{ij}) for use with the gravity model can be based on travel time or distance between analysis areas. Most state or regional planning agencies have well-developed databases describing road networks that include distances and travel times. If an assignment network is available it should be modified to represent available truck facilities and operational characteristics and used to develop the necessary input to trip distribution. For example, the planning agency should annotate roads on the network that may restrict certain classes of trucks due to height or weight, or conversely may be designated as truck routes. The agency may also add a time-value to particular segments to represent the effect of large tolls.

If a network is not available, the agency may develop trip distribution estimates based on map distances. The minimum data needed for the quick response method are distances in miles between zones. These may be derived from actual miles on the existing network or using methods identified in NCHRP Report No. 187. In addition, either map tracings using a map wheel or driven surveys with odometer may be used for distances. Distances should be calculated to and from zone centroids, using appropriate routes.

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[6] Sosslau, Hassam, Carter and Wickstrom. *Quick-Response Urban Travel Estimation Techniques and Transferable Parameters Users Guide*. National Cooperative Highway Research Program Report 187. Transportation Research Board. 1978.

The following data sources for networks may supplement local data. (Data sources for rail and other modal networks are included in Chapter 6).

- The *National Highway Planning Network (NHPN)* is available through the Bureau of Transportation Statistics and is based on the U.S. Geological Survey (USGS) 1:2,000,000 digital line graphs (DLG's). The network includes number of lanes, degree of access control, and FHWA functional classification codes. It is available on disk, hard copy and CD-ROM, as well as on the Internet (see Appendix K, Part 2 for details).

- The *Highway Performance Monitoring System (HPMS) Database* includes the county designation, section ID, toll status, signage, and other identifying information for all public road mileage in the state (termed "universe data"). Principal arterials and higher road levels include the average annual daily traffic (AADT), median type, number of lanes, route number, and others. Currently the data is in ASCII format. Data can be downloaded to a disk and can be sorted or selected by county, Federal Aid Urbanized Area, State, etc. The Department of Transportation is converting the database into GIS format as part of the National Highway Planning Network for ease of use (see Appendix K, Part 2).

- The *National Commodity Flow Network* includes information on highway, railroad, waterway, aviation and pipeline networks with intermodal connections. Networks are based on 1:2,000,000 maps and are generally accurate to 1,000 meters (see Appendix K, Part 2).

In the quick response method, for the different types of commercial vehicles, the following friction factors based on travel time (t_{ij}) in minutes between analysis areas are recommended:

Four-tire commercial vehicles:

$$F_{ij} = e^{-0.08 * t_{ij}}$$

Single unit trucks (6+tires):

$$F_{ij} = e^{-0.1 * t_{ij}}$$

Combinations:

$$F_{ij} = e^{-0.03 * t_{ij}}$$

These friction factors are based on average trip times from Phoenix, with a judgmental adjustment to account for the fact that the Phoenix survey did not cover trips beginning or ending outside the MPO region.[7]

If information on external-to-external trips can be obtained from other sources (e.g., from a special survey or statewide network analysis), these trips should be treated separately from other trips in the trip distribution step. Section 8.2 of this report demonstrates how trip distribution might be carried out for an external-to-external trip table.

If separate information on external-to-external trips is not available, then it will be necessary to apply the trip distribution model to both external and internal trips. In this case, we recommend that the analyst review a map showing the location of external stations and identify all pairs of external stations that are unlikely to share trips. Usually these will be pairs of stations that are adjacent to one another or on the same side of the metropolitan area. Examples include external stations on two highways that intersect outside the metropolitan area or serve the same nearby city. The analyst should then put a very small number or zero in the friction factor matrix to greatly reduce or eliminate trips between such pairs of external stations.

In applying the gravity model to external stations, it is necessary to estimate: (1) the travel time from origin to external station for trips that begin outside the study area, and (2) the travel time from external station to destination for trips that end outside the study area. The following default values can be used if no other information is available:

- Four-tire commercial vehicles -- 40 minutes
- Single unit trucks (6+tires) -- 30 minutes
- Combinations -- 200 minutes

These default values are based on an analysis of data about the primary range of operations for trucks from the Bureau of the Census' Truck Inventory and Use Survey. While these default values may be reasonable on average, their use could considerably understate or overstate travel times for a given external station. Accordingly, the analyst is urged to examine state or regional highway maps and make judgmental adjustments if necessary.

4.4.1 Example

Assume that the origin-destination travel times for the three commercial vehicle types in the hypothetical study area are as shown in the tables below (<u>*Note*</u>: Z*i* = Origin Zone i , S*j*

[7] Friction factors for Phoenix were adopted in this manual to be consistent with trip generation default values.

= External Station destination j, the entry Zi - Sj in the table corresponds to the average travel time from Zone i to anywhere outside the study area through Sj, and the entry Si - Zj in the table corresponds to the average travel time from outside the study area to destination Zone j through external station Si) :

Travel Time (tij) Matrix for Four-Tire Trucks, in Minutes

		Destination Zone (j)						
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4
	Z_1	10	18	24	54	60	70	75
	Z_2	18	12	18	60	55	65	68
	Z_3	24	18	12	70	62	55	55
Origin Zone (i)	S_1	54	60	70	---	98	115	115
	S_2	60	55	62	98	---	105	108
	S_3	70	65	55	115	105	---	90
	S_4	75	68	55	115	108	90	---

Travel Time (tij) Matrix for Single-Unit Trucks, in Minutes

		Destination Zone (j)						
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4
	Z_1	12	22	28	54	50	60	65
	Z_2	22	14	20	50	45	55	58
	Z_3	28	20	14	60	52	45	45
Origin Zone (i)	S_1	54	50	60	---	78	95	95
	S_2	50	45	52	78	---	85	88
	S_3	60	55	45	95	85	---	70
	S_4	65	58	45	95	88	70	---

Travel Time (tij) Matrix for Combination Trucks, in Minutes

		Destination Zone (j)						
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4
	Z_1	14	25	30	214	220	230	235
	Z_2	25	16	22	220	215	225	228
	Z_3	30	22	16	230	222	215	215
Origin Zone (i)	S_1	214	220	230	---	422	438	435
	S_2	220	215	222	422	---	428	428
	S_3	230	225	215	438	428	---	413
	S_4	235	228	215	435	428	413	---

Using the formulae for friction factor given earlier, the matrix of friction factors to be used in the gravity model have been calculated as shown in the following tables:

Friction Factors (Fij) Matrix for Four-Tire Trucks

		Destination Zone (j)						
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4
	Z_1	0.4493	0.2369	0.1466	0.0133	0.0082	0.0037	0.0025
	Z_2	0.2369	0.3829	0.2369	0.0082	0.0123	0.0055	0.0043
	Z_3	0.1466	0.2369	0.3829	0.0037	0.0070	0.0123	0.0123
Origin Zone (i)	S_1	0.0133	0.0082	0.0037	---	0.0004	0.0001	0.0001
	S_2	0.0082	0.0123	0.0070	0.0004	---	0.0002	0.0002
	S_3	0.0037	0.0055	0.0123	0.0001	0.0002	---	0.0007
	S_4	0.0025	0.0043	0.0123	0.0001	0.0002	0.0007	---

Friction Factors (Fij) Matrix for Single-Unit Trucks

		Destination Zone (j)						
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4
	Z_1	0.3012	0.1108	0.0608	0.0045	0.0067	0.0025	0.0015
	Z_2	0.1108	0.2466	0.1353	0.0067	0.0111	0.0041	0.0030
	Z_3	0.0608	0.1353	0.2466	0.0025	0.0055	0.0111	0.0111
Origin Zone (i)	S_1	0.0045	0.0067	0.0025	---	0.0004	0.0001	0.0001
	S_2	0.0067	0.0111	0.0055	0.0004	---	0.0002	0.0002
	S_3	0.0025	0.0041	0.0111	0.0001	0.0002	---	0.0009
	S_4	0.0015	0.0030	0.0111	0.0001	0.0002	0.0009	---

Friction Factors (Fij) Matrix for Combination Trucks

		Destination Zone (j)						
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4
	Z_1	0.6570	0.4724	0.4066	0.0016	0.0014	0.0010	0.0009
	Z_2	0.4724	0.6188	0.5169	0.0014	0.0016	0.0012	0.0011
	Z_3	0.4066	0.5169	0.6188	0.0010	0.0013	0.0016	0.0016
Origin Zone (i)	S_1	0.0016	0.0014	0.0010	---	0.0000	0.0000	0.0000
	S_2	0.0014	0.0016	0.0013	0.0000	---	0.0000	0.0000
	S_3	0.0010	0.0012	0.0016	0.0000	0.0000	---	0.0000
	S_4	0.0009	0.0011	0.0016	0.0000	0.0000	0.0000	---

For the four-tire truck, the gravity model is applied as follows:

1. Create an origin-destination matrix (trip table) which shows the row (origin) and column (destination) totals from the results of trip generation step for the internal zones and traffic estimates at external stations. The distribution of these trips (e.g. Vij) are still unknown. (See matrix below)

2. For each origin-destination pair, multiply the column (destination) total by the friction factor for origin-destination pair (e.g. Dj*Fij). Calculate the total for each row. For example, for Z_1, $\sum$(Dj*Fij) = (24,944*0.4493) + (29,607*0.2369) + (29,654* 0.1446) + (901*0.0082) + (650*0.0037) + (2530*0.0025) $\cong$ 22,626. The results are shown below:

Four-Tire Truck Trip Table

Iteration =	**0**	**Destination Zone (j)**								
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Total (Oi)	Sum(Dj*Fij)
Origin Zone (i)	Z_1	?	?	?	?	?	?	?	24,944	**22,625.56**
	Z_2	?	?	?	?	?	?	?	29,607	24,321.98
	Z_3	?	?	?	?	?	?	?	29,654	22,082.25
	S_1	?	?	?	0	?	?	?	2,948	685.74
	S_2	?	?	?	?	0	?	?	901	778.49
	S_3	?	?	?	?	?	0	?	650	622.03
	S_4	?	?	?	?	?	?	0	2,530	555.32
	Total (Dj)	24,944	29,607	29,654	2,948	901	650	2,530	91,234	

3. <u>First Iteration</u>: Distribute the row totals to each cell in the trip table by using the trip distribution formula for V_{ij} given earlier. For example, V_{12} = (24,944 * 29,607 * 0.2369)/22625.56 $\cong$ 7,734. Calculate the total for each column (destination). Determine the percentage difference (% Diff.) between the column totals and the original column total. For example, the % Difference for Column 2 (Destination Z_2) is equal to [(33,177-29,607)/29,607] * 100% $\cong$ 12.1%. If one or more of the % Differences exceed the threshold value (say ± 5%), adjust the destination totals using the adjustment formula discussed earlier (i.e. D_j^q).

Four-Tire Truck Trip Table

Iteration = 1

		Destination Zone (j)								
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Oi	Sum(Dj*Fij)
Origin Zone (i)	Z_1	12,357	**7,734**	4,793	43	8	3	7	24,944	22,723.50
	Z_2	7,194	13,800	8,553	30	13	4	13	29,607	23,960.30
	Z_3	4,911	9,420	15,248	15	8	11	42	29,654	22,426.45
	S_1	1,426	1,047	471	0	2	0	1	2,948	655.17
	S_2	238	421	241	1	0	0	1	901	774.10
	S_3	96	171	380	0	0	0	2	650	665.19
	S_4	282	585	1,659	1	1	2	0	2,530	546.87
	Total Dj	26,503	**33,177**	31,344	90	33	20	66		
	% Diff.	6.3%	**12.1%**	5.7%	-96.9%	-96.4%	-96.9%	-97.4%		
	Adj. Dj	23,476	**26,421**	28,055	96,126	24,908	20,716	97,603		

Note that for the first iteration (q=1), all the column totals are above the 5% threshold limits. Therefore we need to adjust the column totals. For example, for Column 2, the adjusted column total is:

$$D_2^1 = D_2^0 \bullet \frac{D_2}{C_2^0} = 29{,}607 \bullet \frac{29{,}607}{33{,}177} = 26{,}421$$

4. Second Iteration: Repeat Step 3 above, but using the adjusted column total in the trip distribution formula. Again, for V_{12}, the new value is (24,944 * 26,421 * 0.2369)/22,724 ≅ 6,872. The results of the calculation are shown below. Note that the % Differences are all below the threshold value, which means that the no further iteration is necessary.

Four-Tire Truck Trip Table

Iteration = 2

		Destination Zone (j)								
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Oi	Sum(Dj*Fij)
Origin Zone (i)	Z_1	11,579	**6,872**	4,515	1,403	225	84	266	24,944	22,704.55
	Z_2	6,873	12,501	8,213	978	378	141	523	29,607	23,950.49
	Z_3	4,551	8,277	14,204	470	231	336	1,584	29,654	22,450.34
	S_1	1,405	978	467	0	44	9	44	2,948	654.51
	S_2	225	378	229	44	0	5	20	901	773.76
	S_3	85	142	337	9	5	0	71	650	666.39
	S_4	269	530	1,593	45	20	72	0	2,530	547.64
	Total Dj	24,987	29,678	29,558	2,949	904	648	2,509		
	% Diff.	**0.2%**	**0.2%**	**-0.3%**	**0.0%**	**0.3%**	**-0.3%**	**-0.8%**		

As stated earlier, more than two iterations may be needed in other cases to meet the level of accuracy criterion. A computer program may have to be implemented if a very accurate trip table is desired, especially if it involves many iterations. The table below shows that five iterations are needed to balance the trip table for the above example.

Four-Tire Truck Trip Table

Iteration = 5		Destination Zone (j)								
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Oi	Sum(Dj*Fij)
Origin Zone (i)	Z_1	11,566	6,861	4,536	1,404	224	84	268	24,944	22,701.13
	Z_2	6,861	12,475	8,247	977	377	142	528	29,607	23,950.08
	Z_3	4,536	8,247	14,238	469	230	337	1,597	29,654	22,453.43
	S_1	1,404	977	469	0	44	9	45	2,948	654.41
	S_2	224	377	230	44	0	5	20	901	773.74
	S_3	84	142	337	9	5	0	72	650	666.52
	S_4	268	528	1,597	45	20	72	0	2,530	547.75
	Total Dj	24,944	29,607	29,654	2,948	901	650	2,530		
	% Diff.	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%		

For the single-unit trucks and combination trucks, the same procedures will be followed to distribute the trips to various origin-destination pairs. The following tables show the results of each iteration:

Combination Truck Trip Table

Iteration = 0

		Destination Zone (j)							
		Z1	Z2	Z3	S1	S2	S3	S4	Total (Oi)	Sum(Dj*Fij)
Origin Zone (i)	Z1	?	?	?	?	?	?	?	1,561	3,325.11
	Z2	?	?	?	?	?	?	?	2,379	3,701.76
	Z3	?	?	?	?	?	?	?	2,866	3,647.99
	S1	?	?	?	0	?	?	?	2,412	8.68
	S2	?	?	?	?	0	?	?	3,331	9.57
	S3	?	?	?	?	?	0	?	217	8.91
	S4	?	?	?	?	?	?	0	2,070	8.44
	Total (Dj)	1,561	2,379	2,866	2,412	3,331	217	2,070	14,835	

Single Unit Truck Trip Table

Iteration = 0

		Destination Zone (j)							
		Z1	Z2	Z3	S1	S2	S3	S4	Total (Oi)	Sum(Dj*Fij)
Origin Zone (i)	Z1	?	?	?	?	?	?	?	5,692	3,063.99
	Z2	?	?	?	?	?	?	?	7,815	3,627.48
	Z3	?	?	?	?	?	?	?	7,767	3,336.91
	S1	?	?	?	0	?	?	?	965	98.02
	S2	?	?	?	?	0	?	?	792	168.57
	S3	?	?	?	?	?	0	?	167	133.32
	S4	?	?	?	?	?	?	0	828	118.85
	Total (Dj)	5,692	7,815	7,767	965	792	167	828	24,026	

Combination Truck Trip Table

Iteration = 1

		Destination Zone (j)							
		Z1	Z2	Z3	S1	S2	S3	S4	Oi	Sum(Dj*Fij)
Origin Zone (i)	Z1	481	528	547	2	2	0	1	1,561	4,047.04
	Z2	474	946	952	2	3	0	1	2,379	4,338.80
	Z3	499	966	1,393	2	3	0	3	2,866	4,160.67
	S1	706	899	802	0	3	0	1	2,412	7.69
	S2	739	1,309	1,278	3	0	0	2	3,331	7.75
	S3	38	68	110	0	0	0	0	217	9.49
	S4	332	624	1,110	1	2	0	0	2,070	7.40
	Total Dj	3,270	5,339	6,193	10	14	1	8		
	% Diff.	109.5%	124.4%	116.1%	-99.6%	-99.6%	-99.5%	-99.6%		
	Adj. Dj	745	1,060	1,326	586,755	782,233	43,714	522,948		

Single Unit Truck Trip Table

Iteration = 1

		Destination Zone (j)							
		Z1	Z2	Z3	S1	S2	S3	S4	Oi	Sum(Dj*Fij)
Origin Zone (i)	Z1	3,185	1,609	877	8	10	1	2	5,692	3,089.45
	Z2	1,359	4,152	2,265	14	19	1	5	7,815	3,611.32
	Z3	806	2,462	4,458	6	10	4	21	7,767	3,369.23
	S1	253	518	190	0	3	0	1	965	94.00
	S2	180	408	201	2	0	0	1	792	164.73
	S3	18	40	108	0	0	0	1	167	142.67
	S4	60	165	601	1	1	1	0	828	112.83
	Total Dj	5,860	9,353	8,700	30	43	8	31		
	% Diff.	2.9%	19.7%	12.0%	-96.9%	-94.5%	-95.3%	-96.2%		
	Adj. Dj	5,529	6,530	6,934	30,907	14,492	3,539	21,926		

Combination Truck Trip Table

Iteration = 2

		Destination Zone (j)							
		Z1	Z2	Z3	S1	S2	S3	S4	Oi	Sum(Dj*Fij)
Origin Zone (i)	Z1	189	193	208	369	410	17	175	1,561	4,066.69
	Z2	193	360	376	438	678	28	307	2,379	4,362.02
	Z3	209	377	565	407	690	48	569	2,866	4,175.37
	S1	381	452	419	0	779	27	353	2,412	7.70
	S2	435	720	730	800	0	50	596	3,331	7.67
	S3	17	28	48	26	47	0	50	217	9.51
	S4	181	318	587	353	581	51	0	2,070	7.40
	Total Dj	1,605	2,448	2,933	2,393	3,186	220	2,049		
	% Diff.	2.8%	2.9%	2.3%	-0.8%	-4.3%	1.7%	-1.0%		

Single Unit Truck Trip Table

Iteration = 2

		Destination Zone (j)							
		Z1	Z2	Z3	S1	S2	S3	S4	Oi	Sum(Dj*Fij)
Origin Zone (i)	Z1	3,068	1,333	777	257	180	16	61	5,692	3,091.16
	Z2	1,326	3,485	2,031	451	348	31	144	7,815	3,609.45
	Z3	775	2,037	3,942	177	184	91	562	7,767	3,369.91
	S1	256	452	176	0	61	3	17	965	93.96
	S2	179	349	184	61	0	3	16	792	164.68
	S3	16	31	90	3	3	0	23	167	142.80
	S4	61	145	565	17	16	24	0	828	112.81
	Total Dj	5,681	7,831	7,765	965	793	168	822		
	% Diff.	-0.2%	0.2%	0.0%	0.0%	0.2%	0.3%	-0.7%		

4.4.2 Alternative Approaches

As stated above, instead of travel time, distance can be used to calculate a friction factor in the gravity model for trip distribution. Friction factors based on travel time can be easily converted to friction factors based on distance by assuming average truck speeds (i.e. Travel Time = Distance/Speed). In addition, the ideal trip distribution procedure will require several iterations in order to not only balance the row and column totals but also to come up with the original (target) column totals. Note that in the quick response method and the example given in this manual, no more than three manual iterations were carried out and the final column totals are not necessarily identical to the original numbers (i.e., within ± 5% of the original, which was the criterion used). A computer program may be implemented to allow numerous iterations of the gravity model and come up with a balanced trip table (i.e., row totals equal column totals).

The literature on freight demand forecasting contains a variety of alternative approaches for distributing commercial vehicle trips into the origin-destination trip table. Apart from the gravity model (which is probably the most popular), commercial vehicle trips can be distributed into the origin-destination matrix using: (1) the *Intervening Opportunity Model* which assumes that the trip interchange between origin and destination zone is equal to the total number of trips emanating from the origin multiplied by the probability that each trip will find an acceptable terminus at the destination zone, and (2) the *Fratar Model* which assumes that the change in the number of trips in an origin-destination pair is directly proportional to the change in the number of trips in the origin and destination.

The following describes some of the methodologies found in literature:

- The trip distribution methodology adopted for freight movements in the *Puget Sound Region*[8] is also a simple gravity-type model. Trip distribution involves the allocation of the trips generated to the destinations using an algorithm which incorporates transportation performance measures. These measures include distance, travel time, travel cost, or some function of these variables.

- Trip distribution for the Portland's *Columbia Corridor Transportation Study*[9] involves the creation of a regional distribution based upon the Port of Portland survey of origins and destinations of trucks for two terminals. Information gathered from the survey includes truck type, time, origin, route taken to the terminal, commodity delivered, exiting destination, route taken from the terminal, and commodity received. A trip table was produced, approximating truck movements to and from the 38 industrial area origin-destination districts, by applying the percentage distribution of trips derived from one of the terminal

[8] Transmode Consultants, Inc. *Planning for Freight Movements in the Puget Sound Region*. Puget Sound Regional Council. January 1995.

[9] City of Portland, Office of Transportation. *Columbia Corridor Transportation Study*. Technical Report 2: Truck Routing Model. April 1994.

surveys to the commercial vehicle trip control totals. The "gradient method" was used to modify the trip table until the estimated truck volumes closely approximated the observed truck counts.

- List and Turnquist[10] developed a new technique for estimating multi-class truck trip matrices for truck flows in urban areas which allow for wide variations in input data. The methodology assumes that the links in the analysis network consist of at least three attributes: (1) a "directional flag" (i.e., $i \rightarrow j$, $j \rightarrow i$, or both), (2) a use label (e.g. truck class), and (3) a travel time which may vary according to the time of day. In addition, the methodology assumes that the study area is divisible into non-overlapping zones and each zone must have a centroid where trips originate and terminate. The input data are of three types namely: (1) link volumes or classification counts, (2) partial O-D estimates for various zones, time periods, and truck classifications, and (3) originating/terminating data. Nine O-D matrices were estimated from three time periods (6:00-10:00 A.M., 10:00 A.M.-3:00 P.M., and 3:00-8:00 P.M.) and three truck classifications (van, medium truck, and heavy truck). A case study analysis focusing on the Bronx in New York City was conducted to test the procedures.

- Memmott and Boekenkroeger[11] discussed the development of freight flow tables for a freight generation and distribution growth factor model in Florida. Four sets of truck freight O-D tables were produced indicating the volume of freight shipped between each origin and destination zone by mode of transportation and commodity group. The four O-D tables were: (1) true O-D truck freight volumes (not including ports), (2) truck freight volumes to ports, (3) truck freight volumes from ports, and (4) total truck freight volumes. Due to the long and complicated process involved in developing the various O-D freight flow tables, its use is not suitable for a quick response method. A full description of the procedures can be found in two reports prepared for the Florida Statewide Multi-Modal Planning Process Project.

- The *Chicago Area Transportation Study (CATS)*[12] planning and modeling procedures distribute truck trips in the region based on employment distribution. Using the 1986 survey data for average trip lengths and the regional highway network, O-D trip matrices were developed for each of the vehicle weight categories. The O-D matrices were then converted into vehicle equivalents by weight category, and subsequently combined. The combined

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[10] List and Turnquist.. *Estimating Truck Travel Patterns In Urban Areas.* Transportation Research Record No. 1430. 1994.

[11] Memmott and Boekenbroeger. *Practical Methodology for Freight Forecasting.* Transportation Research Record No. 889.

[12] Rawling and DuBoe. *Application of Discrete Commercial Vehicle Data to CATS' Planning and Modeling Procedures*. CATS Research News. Spring 1991.

trip table matrix is added to the O-D matrix for autos and the O-D matrix for external truck trips.

4.5 Calibration

Calibration is the process through which travel forecasting models are adjusted to achieve a better match with ground counts and perhaps other measures of travel. Use of ground counts on screenlines or cutlines is the preferred method for calibration. Unfortunately, many planning agencies do not have counts of commercial vehicles on screenlines or cutlines. Accordingly, a coarser approach is adopted in the quick response procedure -- calibration based on an estimate of regional VMT by commercial vehicles. However, if study resources permit, the analyst is strongly urged to obtain or collect commercial vehicle count data for major links within the study area, and to compare these counts with assigned volumes (see Chapter 6). FHWA's *Calibration and Adjustment of System Planning Models*[13] is recommended as an excellent guide on how to use a comparison of ground counts with assigned volumes to diagnose and correct problems in highway system planning models.

In the quick-response procedure, calibration is performed for the three commercial vehicle classes as follows (corresponding to Step 5 through Step 7 in Figure 4.1):

- Develop a preliminary estimate of commercial vehicle VMT by assigning trips to a network or using a table of zone-to-zone distances (*Step 5*) ,

- Develop control totals for commercial VMT based upon: (1) estimates of total VMT in the region for each highway functional class, and (2) vehicle classification data indicating the percentage of total VMT associated with commercial vehicles, i.e. Table 4.2 (*Step 6*),

- Compare the preliminary estimate of commercial vehicle VMT with the control totals and, if necessary, develop and apply adjustment factors to trip generation rates or trip distribution factors (*Step 7*).

Initial estimates of commercial VMT can be calculated by multiplying the numbers in the trip distribution O-D matrix by the zone-to-zone distances. Alternatively, if a preliminary network assignment has been made the VMT can be calculated by multiplying the number of trips assigned to a highway segment by the length of the segment.

Establishing control totals for VMT requires at a minimum an estimate of total VMT in the region by functional class. If available, truck volumes across screenlines would be desirable. Agencies are advised to begin with the state HPMS AADT and EPA-

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[13] Dane Ismart; *Calibration and Adjustment of System Planning Models*; Federal Highway Administration Publication No. FHWA-ED-90-015; December 1990.

recommended methodologies. Many regions are currently required to estimate regional VMT for air quality conformity purposes. The recommended method relies on HPMS data collection counts. Areawide HPMS data includes travel by functional system and travel activity by vehicle type. HPMS AADT counts are available for all principal arterials and higher road designations.

Control totals for regional VMT can be determined from HPMS collected data using the methodology described in the EPA publication *Section 187 VMT Forecasting and Tracking Guidance*. The guide includes tiers of procedures based on air quality status. Regions that are not currently required to report current VMT for air quality purposes may wish to apply the least stringent methodologies. The guidance also includes procedures for forecasting VMT.

Control VMT for commercial vehicles can also be estimated using the national average percentage distribution of traffic by vehicle class as shown in Table 4.2. Again, these percentages represent the vehicle type in each highway functional classification as a percentage of annual vehicle miles traveled for the entire country.

Several different types of adjustments can be made as part of the calibration process including:

- Increasing or decreasing the commercial vehicle trip generation rates for traffic analysis zones,

- Increasing or decreasing the commercial vehicle volume estimates at external stations, and

- Modifying the travel time friction factors (by changing the exponents) to increase or decrease average trip lengths.

The simplest approach, and the one recommended for the quick response method, is to develop three adjustment factors -- one for each of the three commercial vehicle classes -- and apply these factors to both trip rates for traffic analysis zones and volumes at external stations. This approach eliminates the need to redo the trip distribution step.

4.5.1 Example

Suppose the zone-to-zone distances (in miles) for the hypothetical study area are as shown in the table below:

Zone-to-Zone Distance (miles)

		Destination Zone (j)						
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4
	Z_1	5.0	9.0	12.0	7.0	10.0	15.0	17.5
	Z_2	9.0	6.0	9.0	10.0	7.5	12.5	14.0
	Z_3	12.0	9.0	6.0	15.0	11.0	7.5	7.5
Origin Zone (i)	S_1	7.0	10.0	15.0	0.0	9.0	17.5	17.5
	S_2	10.0	7.5	11.0	9.0	0.0	12.5	14.0
	S_3	15.0	12.5	7.5	17.5	12.5	0.0	5.0
	S_4	17.5	14.0	7.5	17.5	14.0	5.0	0.0

Initial estimates of daily VMT for each commercial vehicle type are determined by multiplying the trip tables from the trip distribution step by the table of zone-to-zone distance shown above. For example, the daily VMT for four-tire trucks originating in zone Z_1 and destined to Z_2 is: 6,872*9 = 61,848. The resulting daily VMT estimates for all three vehicle types are given below:

Estimated Daily VMT

Four-Tire Truck

		Destination Zone (j)							
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Total
	Z_1	57,895	**61,848**	54,180	9,821	2,250	1,260	4,655	191,909
	Z_2	61,857	75,006	73,917	9,780	2,835	1,763	7,322	232,480
	Z_3	54,612	74,493	85,224	7,050	2,541	2,520	11,880	238,320
Origin Zone (i)	S_1	9,835	9,780	7,005	0	396	158	770	27,944
	S_2	2,250	2,835	2,519	396	0	63	280	8,343
	S_3	1,275	1,775	2,528	158	63	0	355	6,153
	S_4	4,708	7,420	11,948	788	280	360	0	25,503
	Total	192,432	233,157	237,320	27,992	8,365	6,123	25,262	730,650

Estimate of Daily VMT

Single-Unit Truck

		Destination Zone (j)							
		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Total
	Z_1	15,340	11,997	9,324	1,799	1,800	240	1,068	41,568
	Z_2	11,934	20,910	18,279	4,510	2,610	388	2,016	60,647
	Z_3	9,300	18,333	23,652	2,655	2,024	683	4,215	60,862
Origin Zone (i)	S_1	1,792	4,520	2,640	0	549	53	298	9,851
	S_2	1,790	2,618	2,024	549	0	38	224	7,242
	S_3	240	388	675	53	38	0	115	1,508
	S_4	1,068	2,030	4,238	298	224	120	0	7,977
	Total	41,464	60,795	60,832	9,863	7,245	1,520	7,935	189,653

Estimate of Daily VMT

Combination Truck

Destination Zone (j)

Origin Zone (i)

	Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Total
Z_1	945	1,737	2,496	2,583	4,100	255	3,063	15,179
Z_2	1,737	2,160	3,384	4,380	5,085	350	4,298	21,394
Z_3	2,508	3,393	3,390	6,105	7,590	360	4,268	27,614
S_1	2,667	4,520	6,285	0	7,011	473	6,178	27,133
S_2	4,350	5,400	8,030	7,200	0	625	8,344	33,949
S_3	255	350	360	455	588	0	250	2,258
S_4	3,168	4,452	4,403	6,178	8,134	255	0	26,589
Total	15,630	22,012	28,348	26,901	32,508	2,318	26,400	154,114

Assume that based on regional studies the total daily passenger VMT for the study area is approximately 10 million; and about 95% of the passenger VMT in the region is in urban areas, while the remaining 5% is in rural areas. Likewise, assume that no breakdown of roads by functional classification is available.

From the above information, the daily control VMT for each type of commercial vehicle can be calculated using the percent traffic distribution given in Table 4.2. Since no highway functional classification is available, the average rural and urban percentages from Table 4.2 are used as follows:

Control VMT for Four-Tire Truck:

$$= 10{,}000{,}000 * [\ (0.05*4.7/86.6) + (0.95*6.2/89.8)\ ]$$

$$= 683{,}038$$

Control VMT for Single-Unit Truck:

$$= 10{,}000{,}000 * [\ (0.05*3.4/86.6) + (0.95*1.7/89.8)\ ]$$

$$= 199{,}475$$

Control VMT for Combination Truck:

$$= 10{,}000{,}000 * [\ (0.05*5.3/86.6) + (0.95*2.3/89.8)\ ]$$

$$= 273{,}919$$

For each trip table, the estimated daily VMT is adjusted using the ratio of the control VMT (calculated above) and the estimated total VMT. For example, the adjustment factor for four-tire truck is equal to 683,038/730,650 ≅ 0.935. The adjusted trip tables are shown below:

Adjusted Daily VMT

Four-Tire Truck

Destination Zone (j)

Origin Zone (i)		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Total
	Z_1	54,122	57,818	50,649	9,181	2,103	1,178	4,352	179,404
	Z_2	57,826	70,118	69,100	9,143	2,650	1,648	6,845	217,330
	Z_3	51,053	69,639	79,671	6,591	2,375	2,356	11,106	222,790
	S_1	9,194	9,143	6,549	0	370	147	720	26,123
	S_2	2,103	2,650	2,355	370	0	58	262	7,799
	S_3	1,192	1,659	2,363	147	58	0	332	5,752
	S_4	4,401	6,936	11,169	736	262	337	0	23,841
	Total	179,892	217,964	221,855	26,168	7,819	5,724	23,616	683,038

Adjusted Daily VMT

Single-Unit Truck

Destination Zone (j)

Origin Zone (i)		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Total
	Z_1	16,134	12,618	9,807	1,892	1,893	252	1,123	43,720
	Z_2	12,552	21,993	19,226	4,744	2,745	408	2,120	63,788
	Z_3	9,782	19,283	24,877	2,793	2,129	718	4,433	64,014
	S_1	1,885	4,754	2,777	0	577	55	313	10,361
	S_2	1,883	2,753	2,129	577	0	39	236	7,617
	S_3	252	408	710	55	39	0	121	1,586
	S_4	1,123	2,135	4,457	313	236	126	0	8,390
	Total	43,611	63,944	63,982	10,374	7,620	1,599	8,346	199,475

Adjusted Daily VMT

Combination Truck

Destination Zone (j)

Origin Zone (i)		Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Total
	Z_1	1,680	3,087	4,436	4,591	7,287	453	5,443	26,978
	Z_2	3,087	3,839	6,015	7,785	9,038	622	7,639	38,025
	Z_3	4,458	6,031	6,025	10,851	13,490	640	7,585	49,080
	S_1	4,740	8,034	11,171	0	12,461	840	10,980	48,226
	S_2	7,732	9,598	14,272	12,797	0	1,111	14,830	60,340
	S_3	453	622	640	809	1,044	0	444	4,012
	S_4	5,630	7,913	7,825	10,980	14,457	453	0	47,258
	Total	27,780	39,124	50,384	47,812	57,778	4,119	46,922	273,919

Adjusted Daily VMT

All Commercial Vehicles

Destination Zone (j)

Origin Zone (i)

	Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	Total
Z_1	71,936	73,523	64,893	15,664	11,284	1,884	10,918	250,102
Z_2	73,466	95,950	94,341	21,671	14,433	2,677	16,604	319,143
Z_3	65,293	94,952	110,573	20,234	17,995	3,713	23,124	335,884
S_1	15,819	21,931	20,496	0	13,409	1,042	12,012	84,709
S_2	11,718	15,001	18,756	13,745	0	1,209	15,328	75,756
S_3	1,898	2,689	3,713	1,011	1,142	0	897	11,350
S_4	11,153	16,985	23,451	12,029	14,955	916	0	79,488
Total	251,283	321,031	336,222	84,354	73,217	11,441	78,884	1,156,432

Note that the calibration procedure using control VMT's are not only meaningful for adjusting base-year commercial vehicle trip tables. The adjustment factors can also be used to calibrate estimates of future commercial vehicle trip volumes and VMT's for which no control VMT is available to check against. For example, if trip tables corresponding to future freight travel demands are estimated, the volumes in these tables can be adjusted using the adjustment factor (i.e. dividing the future forecasts by the adjustment factor) determined for the base year, assuming that the ratio between estimated VMT and control VMT remains constant over time.

4.5.2 Alternative Approaches

Variations of the calibration procedures discussed above have been applied in literature and other freight modeling studies, as described below:

- For the *Columbia Corridor Transportation Study*[14] the method involves a linear regression between observed counts and model volumes.

- The paper *Truck Travel in the San Francisco Bay Area*[15] includes a discussion of how daily and afternoon peak hour trip tables were created for two-axle, three-axle, and four or more axle truck trips. The trip tables were assigned to the Bay Area highway network. From these assignments, the estimated vehicle-miles traveled (VMT) and percent Root Mean Square Error (RMSE) were calculated. Percent RMSE represents the variation between observed and estimated data that is expected to occur approximately 68 percent of the time. The truck

[14] See Footnote 9.

[15] Schlappi, Marshall, and Itamura. *Truck Travel in the San Francisco Bay Area*. TRB 72nd Annual Meeting, Paper No. 930477. January 1993.

forecast seemed reasonable when examined both by county subareas and on a link by link basis.

- In the Phoenix report titled *Development of an Urban Truck Travel Model for the Phoenix Metropolitan Area*[16] calibration involved the use of the 1988 modeling process (internal truck generation and distribution models) to perform the final adjustments required to match current vehicle-miles of travel (VMT) to the vehicle trip modeling system. A regionwide factor of 1.38 was applied to the results of the trip generation and distribution models. The 38% adjustment factor represents the effects of:

  ◊ The expansion of truck vehicle trips to the equivalent number of two-axle counts;

  ◊ The adjustment of the estimated internal truck travel with the actual internal truck travel; and

  ◊ The expansion of internal truck travel to compensate for any under-reporting in the latest travel survey or under-estimation in the updated non-truck Phoenix models.

  The calibration process for the new models consists of two steps, namely:

  1. Expanding the commercial vehicle trips by weight class to account for the average number of axles per vehicle in each class; and

  2. Expanding total commercial vehicle trips so that total estimated and observed VMT in the Phoenix region are equal. This expansion factor represents the new effect of internal trips by all commercial vehicles versus those by vehicles registered in Maricopa County, and of any under-reporting or under-estimation in any of the Phoenix models which affect the number of truck and non-truck vehicle trips.

- The report titled *Truck Trip Generation Rates by Land Use in the Central Artery/Tunnel (CA/T) Project Study Area*[17] addresses validation of daily truck trip arrivals. The geographic distribution of calculated daily light, medium, and heavy truck trip arrivals was consistent with observed vehicle classification counts on study area streets and arterials. Classification counts on neighborhood streets indicate miles of truck travel more accurately than truck trip ends. More accuracy has been obtained by establishing a cordon line within the study area, correcting for truck trips that pass through without stopping or those traveling entirely within the cordon, and comparing one-half of the number of crossing to the estimated arrivals into the cordoned zones.

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[16] See Footnote 1.

[17] Nixon, Tom (Central Transportation Planning Staff - Boston). *Truck Trip Generation Rates by Land Use in the Central Artery/Tunnel Project Study Area*. September 1993.

■ 4.6 Traffic Assignment

The calibrated commercial vehicle trip tables can be assigned to a network along with personal vehicle trip tables to produce estimates of total traffic on network links. There are, however, some special considerations that may affect the assignment of commercial vehicle trips including:

- Heavy vehicles typically have more impact on congestion than automobiles on a per VMT basis; and
- On some highways, trucks are not permitted.

The *Highway Capacity Manual*[18] provides "passenger car equivalence" (PCE) factors that can be used to quantify the relative impact of different types of vehicles on congestion. For example, a PCE value of 2.0 indicates that the vehicle in question has the same effect on congestion as 2.0 passenger cars. Specifically, the HCM recommends a PCE value of 1.5 for trucks and buses on level terrain[19], with trucks defined as commercial vehicles with six or more tires.

Hence, to reflect the effect of heavier vehicles on congestion, the trip tables for single unit trucks with six or more tires and combinations can be multiplied by 1.5 and 2.0, respectively, before being assigned to the network. The resulting assignment volumes will then be expressed in PCEs, not number of vehicles. This refinement is appropriate if heavy vehicles are expected to account for a significant portion of traffic (e.g., more than 10 percent) on key links. No adjustments to PCE values are needed for four-tire commercial vehicles, since these vehicles are generally similar to passenger cars in terms of acceleration and deceleration capabilities.

If trucks are prohibited from using key network links, the analyst should consider conducting separate traffic assignments for the prohibited vehicles if it is not possible to code and enforce truck prohibitions in the basic network description. Usually, four tire commercial vehicles such as pickup trucks and vans are not considered to be trucks for the purpose of enforcing truck bans, so that such vehicles would be combined with passenger cars in the assignment process.

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[18] Transportation Research Board; *Highway Capacity Manual*; Special Report 209; updated October 1994.

[19] Level terrain is any combination of grades and horizontal or vertical alignment that permits heavy vehicles to maintain the same speed as passenger cars; this generally includes short grades of no more than 2 percent. The HCM defines rolling terrain as any combination of grades and horizontal or vertical alignment that causes heavy vehicles to reduce their speeds substantially below those of passenger cars but that does not cause them to operate at crawl speeds for any significant length of time. The HCM recommends a PCE value of 3.0 for trucks and buses on rolling terrain. The HCM defines mountainous terrain as that which causes heavy vehicles to operate at crawl speeds for significant distances or frequent intervals, and recommends a PCE value of 6.0 for trucks and buses on mountainous terrain.

An example of traffic assignment for the hypothetical study area is provided in Chapter 5, Site Analysis.

4.7 Time-of-Day Characteristics

Analysts may need to know the temporal distribution of travel by commercial vehicles for several reasons, including:

- To conduct separate traffic assignments for different time periods (e.g., peak and off-peak assignments),
- To calculate peak hour or design hour volumes on a link, based on the assignment of daily traffic to that link, and
- To conduct environmental analyses that are based on hourly traffic distributions (e.g., there are one-hour and eight-hour standards for carbon monoxide)

Table 4-4 shows typical temporal distributions for commercial vehicle traffic in urban areas. These distributions are based on unpublished traffic data collected by State DOTs and compiled by FHWA.

Table 4-4. Temporal Distribution of Commercial Vehicle Traffic in Urban Areas

Hour		Commercial Vehicles		
From	To	Four-Tire Trucks	Single Units (6+ tires)	Combinations
12	1	0.7%	0.7%	2.3%
1	2	0.4%	0.6%	1.8%
2	3	0.4%	0.6%	1.5%
3	4	0.4%	0.5%	1.7%
4	5	0.6%	1.1%	2.3%
5	6	2.0%	3.0%	3.7%
6	7	6.9%	5.0%	4.3%
7	8	6.6%	7.3%	6.0%
8	9	6.4%	7.2%	5.1%
9	10	5.2%	7.8%	7.1%
10	11	5.7%	7.0%	6.3%
11	12	5.4%	7.5%	6.8%
12	1	5.5%	6.8%	6.9%
1	2	5.8%	7.1%	6.3%
2	3	6.4%	7.7%	6.2%
3	4	7.8%	7.7%	5.3%
4	5	8.6%	6.6%	5.1%
5	6	7.1%	5.1%	4.0%
6	7	5.8%	3.5%	3.9%
7	8	3.3%	2.4%	3.0%
8	9	2.9%	1.6%	2.9%
9	10	2.6%	1.3%	2.6%
10	11	2.0%	1.0%	2.5%
11	12	1.3%	1.0%	2.3%
Total		100.0%	100.0%	100.0%

The temporal distribution of commercial vehicles differs considerably from that of passenger vehicles, with the latter showing much more pronounced morning and afternoon peaks due to travel to and from work.